Compact Full-Field Ion Detector System for SmallSats beyond LEO

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Outline

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- SmallSat Platform Technology Challenges
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- SPAGHETI: Deep-Space Application
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Metri sunt Necesse Malum

“Measurements are necessary evils”

Technology Roadmap Challenges

- NASA's Integrated Technology Roadmap (2012): Technology Area (TA) 8.3.1 "In-Situ Instrumentation/Detectors: Particles" Challenges:
  - Energy Threshold (resolve to 1 keV for 30 MeV)
  - Environment Tolerance (radiation-hard ion & electron sensors)
  - Data Handling (improved out-of-band rejection)
  - TRL3→6: 2013→2016
  - Heliophysics, Planetary Science Missions
  - "Robust sensors capable of operating for long periods in environment of space are needed to measure the radiation at the destination as well as during the journey."
- TA08 Roadmap Enabling Approaches:
  - Integrated existing detector technologies
  - Radiation hardened electronics
  - Miniature power supplies
- Also consider: New detectors for smaller platforms

SmallSat Platform Technology Challenges

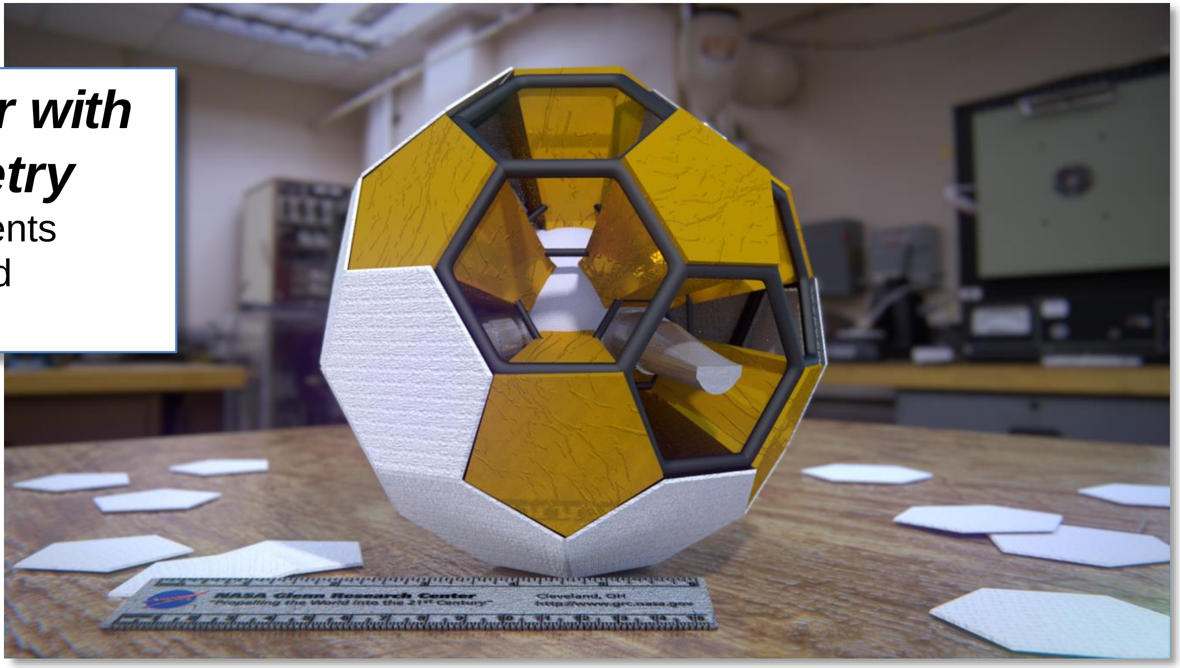
- Need to develop a radiation detector system to fly on small satellite platforms (such as CubeSats) to reduce cost, development time of missions
  - Design point: 1U CubeSat volume, mass for detector system (10 cm x 10 cm x 10 cm, 1 kg) on a deep space platform
  - CubeSats currently flown LEO applications, but future is in Deep Space
- High radiation particle influx from multiple directions (spherical 4π solid angle)
  - Current radiation detector technologies need temperature compensation
  - SmallSat platform size (<100 kg), power limits instrumentation systems
  - More complex systems require new technology
- Solution is the development of new robust, low power, thermally stable solid state radiation detector technology for omni-directional measurements in a compact space radiation detector system
  - Wide band gap semiconductors, micro-optics technologies

Application Concept: Compact Full-Field Ion Detector System (CFIDS)

- Mapping of heavy ions > 100 MeV/amu
  - Integrated system with solid-state Cherenkov detector and large area detectors in surrounding wedges
- High radiation flux rates for 10+ year missions
  - Precision rad-hard, thermally stable wide band gap detectors used
- Low noise, multi-directional measurements at single locations
  - Compact, spherical detector system

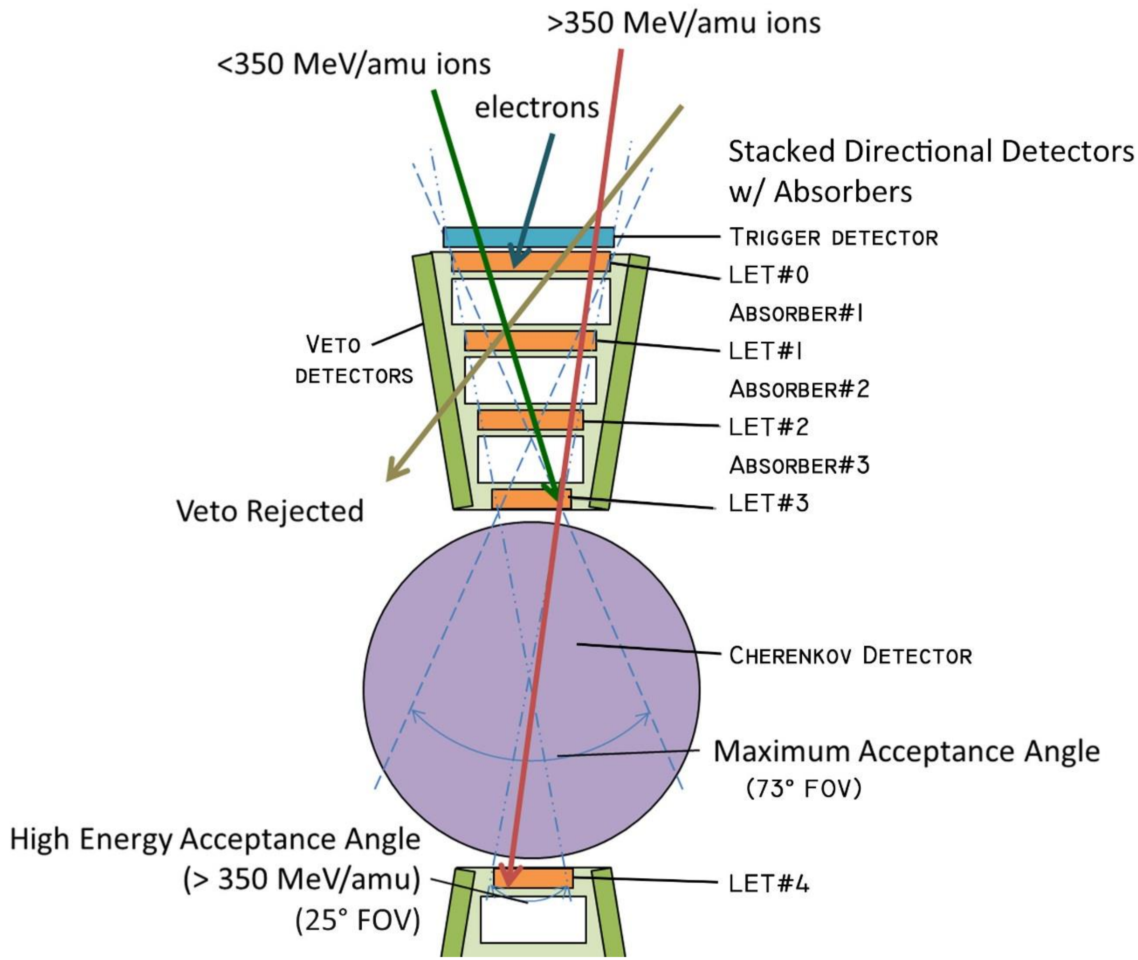
Space radiation detector with spherical geometry

- Technology covered by U.S. Patents 7,872,750 (January 18, 2011) and 8,159,669 (April 17, 2012)



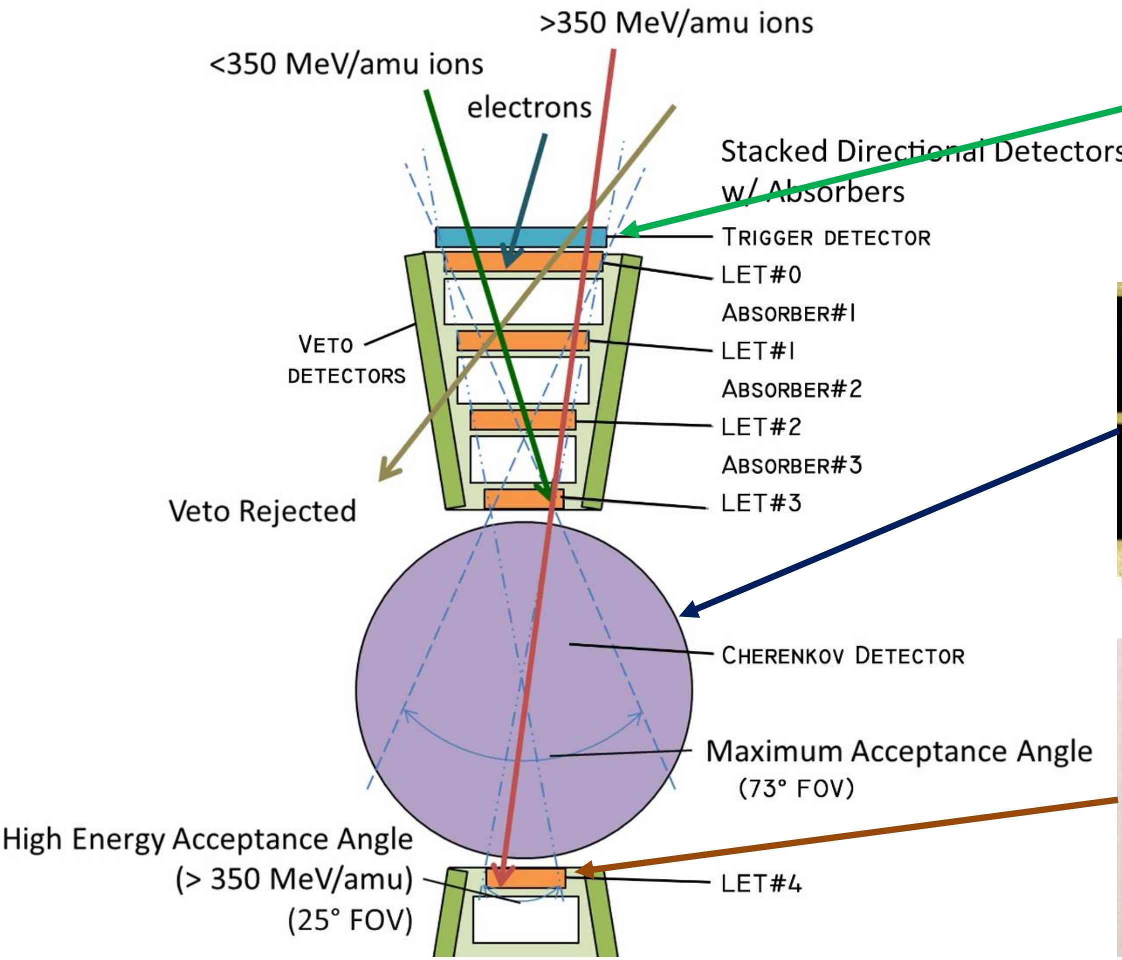
Concept illustration of the CFIDS detector assembly (cables, electronics not shown)

Application Concept: Compact Full-Field Ion Detector System (CFIDS)

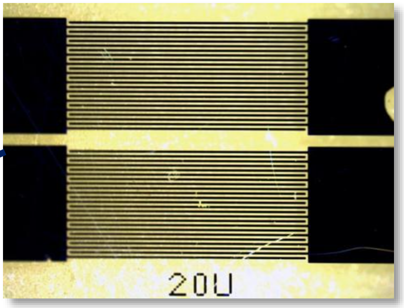


- CFIDS comprised of a spherical Cherenkov detector surrounded by stacked LET detectors with absorbers, Trigger and Veto detectors

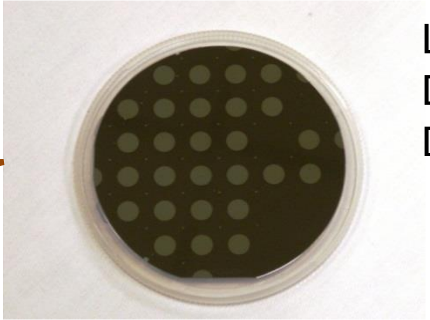
Application Concept: Compact Full-Field Ion Detector System (CFIDS)



GaP Diode for Solid-State Trigger/Veto Detectors



ZnO UV Sensor for Solid-State Cherenkov Detector



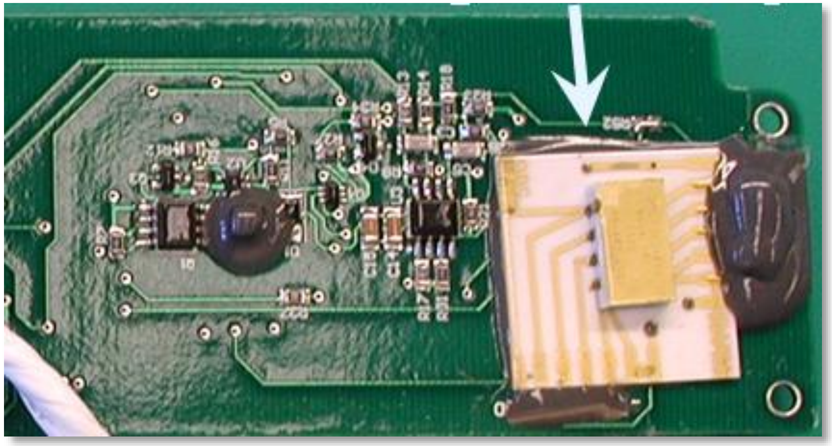
Large Area SiC Diode for LET Detectors

- CFIDS comprised of a spherical Cherenkov detector surrounded by stacked LET detectors with absorbers, Trigger and Veto detectors

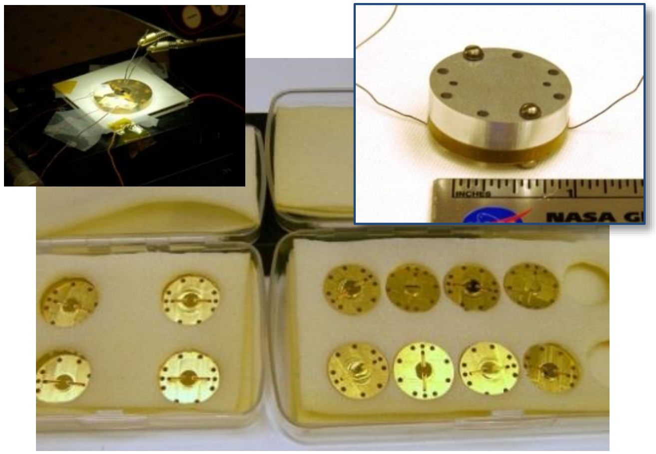
GRC Advanced Radiation Detector Technology Research and Development

- GRC Expertise and Facilities in:
  - Harsh Environment Thin Films
  - SiC Devices & Harsh Environment Packaging
  - Micro-Optics
  - Space-Based Instrumentation
- These strengths are combined into an in-house Radiation Instrumentation Research effort

In-House Microsystems Fabrication



MISSE 7 SiC JFET & Ceramic Packaging (arrow) on a Rad-Hard Electronics Board for ISS flight

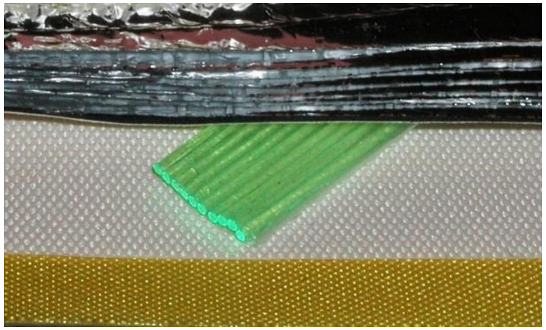


CERES Thin Film Microbolometer Testing and Packaging

Solid-State Trigger/Veto Detectors

- Typically scintillator blocks of plastic or iodide crystal mated to a photomultiplier tube (PMT) or a pixelated avalanche photo detector (APD), also referred to as a silicon photomultiplier (SiPM)
- <u>Goal</u>: Replace the role of PMTs and SiPMs in these types of detectors with WBG devices, saving on size, weight and required power
- Demonstrated a miniature gallium phosphide (GaP) photodiode “paddle style” radiation detector as part of a 2-week OCT/STMD Center Innovation Fund (CIF) study in 2013 (patent pending).
- Use with acrylic ribbon scintillators for the CFIDS concept

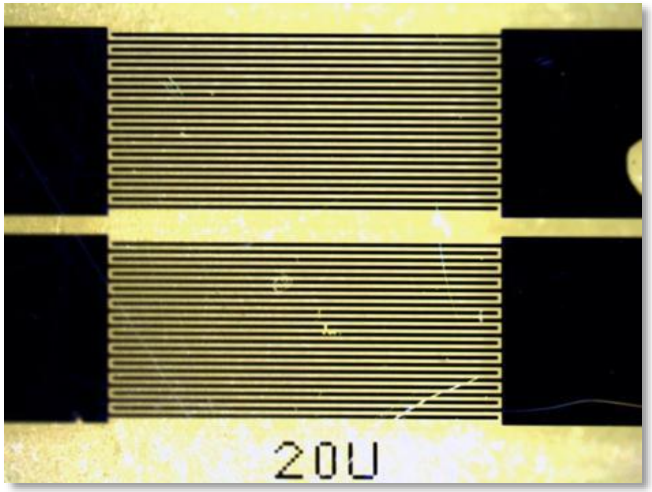
Miniature scintillation/diode ionizing radiation detector



Acrylic ribbon scintillator for ionizing radiation detector

Solid-State Cherenkov Detector

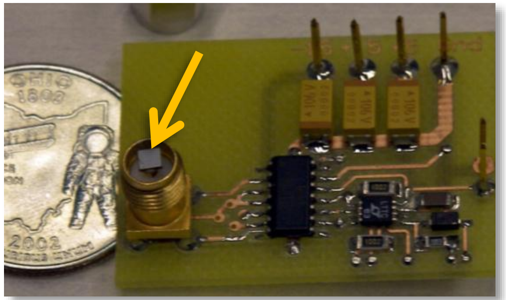
- Typically flat disks or blocks of sapphire or acrylic mounted on PMTs.
- Goal: Replace the role of the relatively large PMTs with solid-state devices that do not require temperature control or compensation.
- A fast, large area solid-state UV detector based on single-crystal, undoped zinc oxide (ZnO) was developed at GRC (patent pending) as part of two 10-week OCT/STMD CIF studies (2011, 2012)
  - Active area of 1 mm by 2 mm (2 mm^2), designed to have a 1 ns response time with 10 V applied bias voltage
  - In a bridge circuit can detect small, fast pulses of UV light like those required for Cherenkov detectors.
  - Sensitive to UV light at 254 nm, slightly less so at 370 nm, and not sensitive to room lighting (about 430-630 nm).
  - Demonstrated improved sensitivity to UV than commercial SiC and GaP detectors



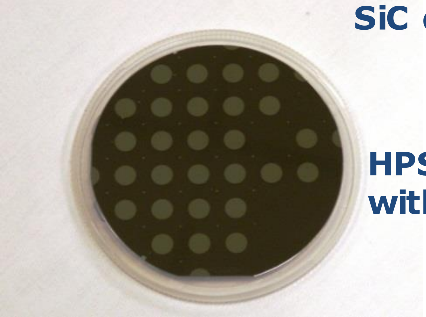
OCT ZnO UV Detector (20 µm electrode spacing)

WBG LET Detectors

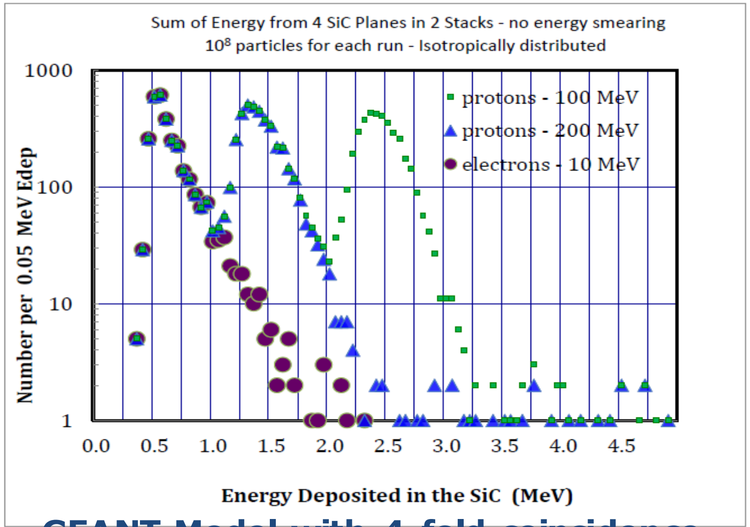
- Typically silicon-based PIN diodes or lithium-drifted silicon wafers (Si(Li)), high bias voltage, thermally sensitive
- Goal: Replace silicon detectors with more robust, temperature-stable low-noise silicon carbide detectors
- Smaller SiC detectors studied as part of AEVA (2005-2007) and ETDP/D (2009-2011), AES (2012) for dosimetry
- Large-area detectors (2 cm², 350 µm thick) using high-purity, semi-insulating (HPSI) SiC wafers with low-Z FEP absorber between detectors for CFIDS
- GEANT models show a 4-fold coincidence is required to resolve LET for high energy protons and electrons



Prototype Dosimeter with SiC detector (arrow)



HPSI 4H-SiC wafer with device pads

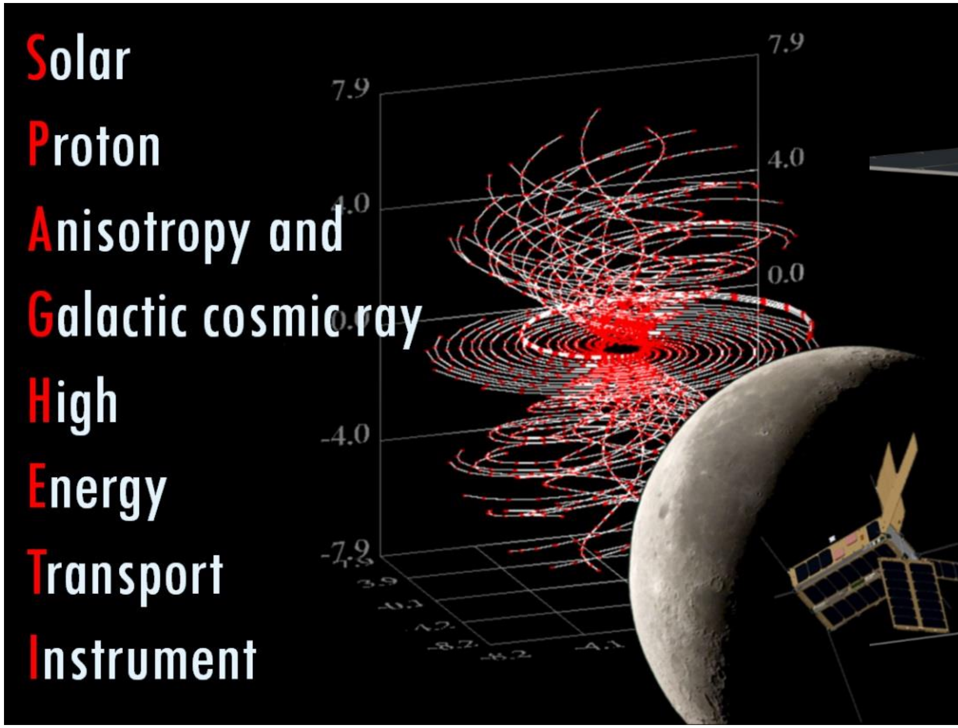


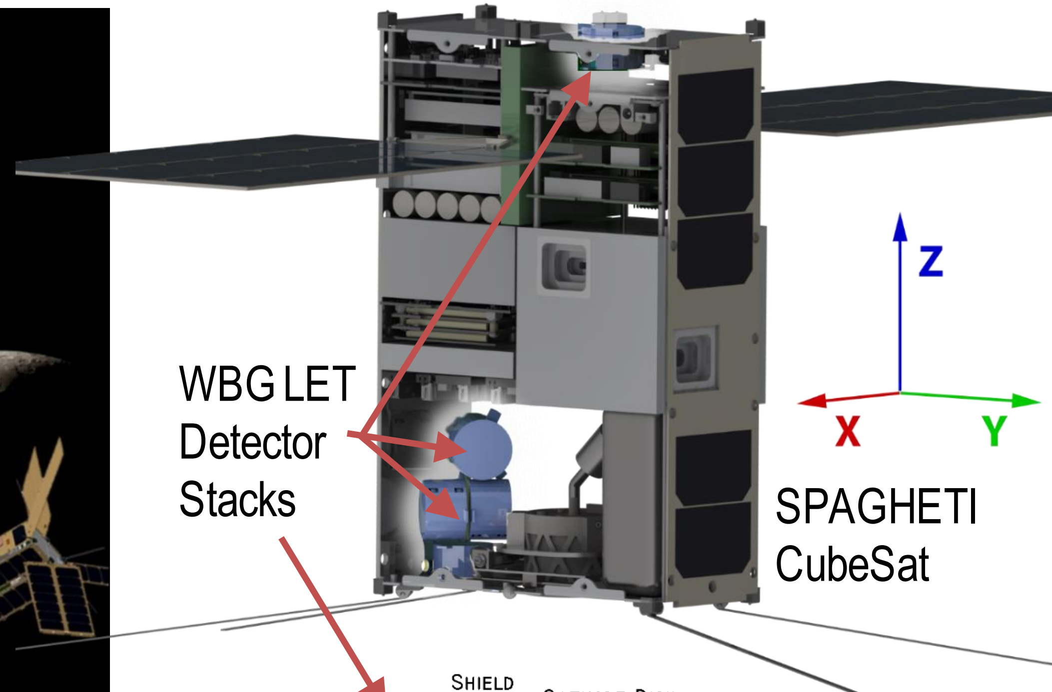
GEANT Model with 4-fold coincidence

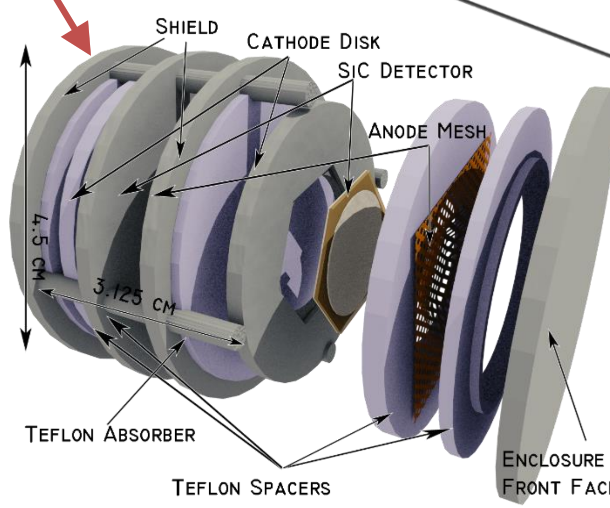
Benefits of WBG Detectors: Lower Power and More Robust

Detector	Active Area	Mass	Volume	Voltage	Dark Current	Minimum Power Draw	Amplitude Signal to Noise	Maximum Operating Tempera-ture	Temperature Sensitivity of Dark Current
Cherenkov Detector:									
SOA: PMT	20 cm^2	170 g	180 cm^3	1000 V	5 nA	5 µW	$4x10^5$	50°C	0.2%/°C
Proposed: ZnO	2 mm^2	11 g	0.80 cm^3	10 V	5 nA	0.05 µW	$2x10^4$	125°C	0.05%/°C
LET:									
SOA: Si PIN	1 cm^2	0.5 g	185 mm^3	100 V	5 nA	0.5 µW	$1x10^5$	60°C	20%/°C
SOA: Si(Li)	30 cm^2	35 g	15 cm^3	300 V	5 µA	1.5 mW	$8x10^3$	60°C	30%/°C
Proposed: SiC	2 cm^2	0.5 g	185 mm^3	5 V	70 pA	0.350 nW	$2x10^5$	120°C	0.1%/°C
Scintillator Trigger/Veto:									
SOA: PMT	20 cm^2	170 g	180 cm^3	1000 V	5 nA	5 µW	$4x10^5$	50°C	0.2%/°C
SOA: APD	9 mm^2	3 g	200 mm^3	30 V	5 nA	0.15 µW	$8x10^4$	85°C	30%/°C
Proposed: GaP	4.8 mm^2	5 g	170 mm^3	5 V	20 pA	0.1 nW	$3x10^5$	125°C	0.5%/°C

SPAGHETI: Deep-Space Application



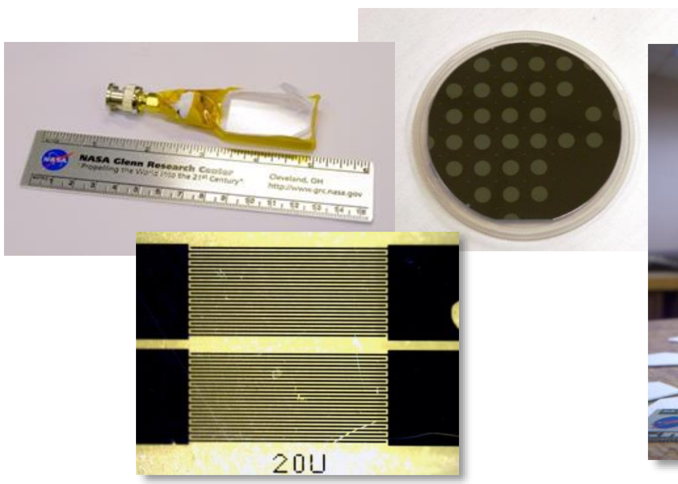


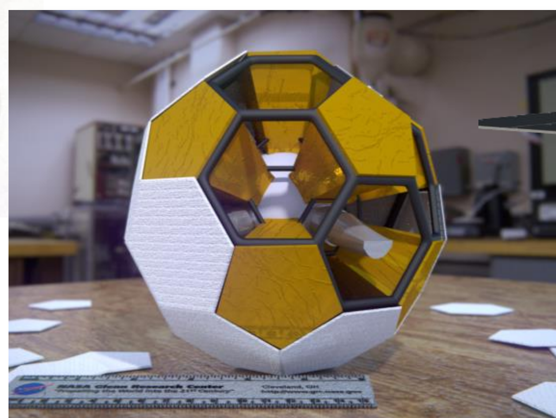


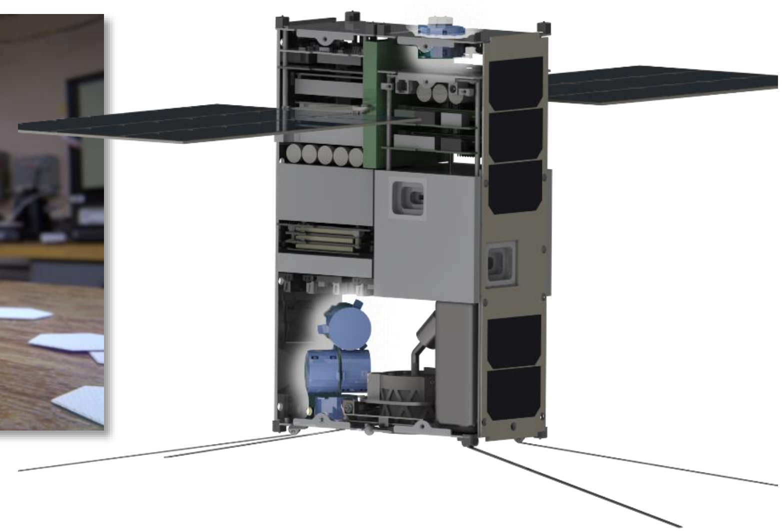
- SPAGHETI is a SmallSat mission for an EM–1-type launch on a 6U CubeSat bus enabled by stacks of WBS LET detectors
- SPAGHETI will explore the transient variations in ion flux anisotropy in deep space and near the lunar surface

Summary

- NASA GRC is leveraging expertise in harsh environment thin films, SiC devices & harsh environment packaging, micro-optics, and space-based instrumentation to advance radiation detector technology
- Application of wide band gap semiconductors as radiation detectors holds the promise of improved low-power, robust detectors for CFIDS
- SPAGHETI using CFIDS radiation instrumentation system in a Deep Space CubeSat will allow in-situ studies of SEP and GCR interactions in lunar environments







Acknowledgements

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